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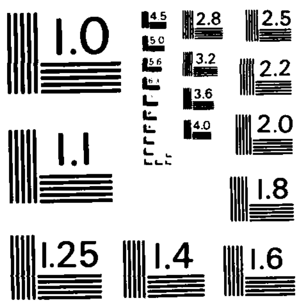

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by

DE WESTON

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AUWE Technical Note No 705/83
April 1983

TURN-AROUND LOSS FOR OCEANIC SOUND ON A BOTTOM SLOPE (U)

by

D E Weston

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TURN-AROUND LOSS FOR OCEANIC SOUND ON A BOTTOM SLOPE (U)

ABSTRACT

1 For oceanic sound reflected from a region of bottom slope the turn-round loss equals the sum of the bottom losses, and can be quite low if the total deflection in horizontal angle is low. Simple formulae are derived, and the effects of the slope being finite are discussed.

1. INTRODUCTION

2. The problem of oceanic sound propagating over a sloping bottom, near a coastline or sea-mount, has been treated by a large number of authors. Several of these have considered the full three-dimensional problem, where a component of slope across the track leads to a refraction or curvature of the horizontal projection of the ray path. For isovelocity water with a constant small bottom slope this projection approximates to a hyperbola, demonstrated for example in the early papers by Kuznetsov (Ref 1) and by Weston (Ref 2). The latter paper provides the illustration in Figure 1. The ray suffers a series of bottom bounces and is gradually turned round, in effect it undergoes specular reflection at the coastline.

3. There is a turn-around loss associated with the bottom bounces, (eg Ref 3), but this has received much less attention than the geometrical questions. The present paper sets out to make some small contributions to the problem of the loss magnitude and its main dependences.

2. PROPAGATION DIRECTLY UP-SLOPE

4. In this and the following section we concentrate on isovelocity water with very small constant bottom slope α, with source and receiver distant, and use ray approximations. Figure 2 shows ray projections into a plane orthogonal to the contour lines and is fully discussed later on. If we go far enough into the deep-water side on the left, the magnitude of the resolved ray grazing angle γ will become very small, eventually less than α. In the turning-round process γ is effectively changed through an angle π, from zero back to zero. Each bottom bounce contributes 2α, so that the number of bounces is

$$n = \pi/2\alpha. \tag{1}$$

If B is bottom loss in dB and $\bar{B}$ is the average value, the total turn-round loss following Harrison (Ref 3) is

$$L = n\bar{B} = \pi\bar{B}/2\alpha. \tag{2}$$

5. These formulae apply to any direction of propagation up the slope, but we now particularise to the direct line at right angles to the contours. Here γ is equal to ϕ, the magnitude of the ordinary grazing angle. In general B may be found by a simple integration, and two examples will be given.

6. If bottom loss is represented by $B_m \sin\phi$ the average $\bar{B}$ is $2B_m/\pi$ and so

$$L = B_m/\alpha. \tag{3}$$

Similarly if bottom loss varies as ϕ to maximum B_m, the average $\bar{B}$ is $B_m/2$ and

$$L = \pi B_m/4\alpha. \tag{4}$$

In equations (3) and (4) the answers are numerically close, and the dependencies on B_m and α of the character expected. High turn-round losses are normally predicted. If we take a low-frequency value of B_m as small as 10 dB, with α as large as 0.2, equation (3) still predicts a loss L as high as 50 dB.

3. PROPAGATION OBLIQUELY UP-SLOPE

7. We will again present two examples, starting with a bottom loss $B_m \sin\phi$. Since γ and ϕ are no longer identical the averaging or integration procedure is a little more complicated, and we need to relate γ and ϕ. From straightforward trigonometry

$$\tan\gamma = \sin\phi/\sin\theta. \tag{5}$$

In addition we note that the bottom bounces cannot change the value of the total angle between the ray path and the contour. This remains constant, so that

$$\sin^2\phi + \sin^2\theta = \sin^2\theta_o. \tag{6}$$

The angle θ_o is shown in figure 1, $2\theta_o$ is the total horizontal deflection.

Combining (5) and (6),

$$\sin\phi = \sin\theta_o \sin\gamma. \tag{7}$$

8. Turn-around loss may now be calculated, starting as before from equation (2).

$$L = \int_o^{\pi/2} \frac{B_m \sin\phi \, d\gamma}{\alpha} = \int_o^{\pi/2} \frac{B_m \sin\theta_o \sin\gamma \, d\gamma}{\alpha}$$

$$= (B_m \sin\theta_o)/\alpha. \tag{8}$$

The important point here is the factor $\sin\theta_o$, new relative to equation (3). For a grazing incidence on the coastline, θ_o small, the value of L can be very small. For normal incidence equation (8) reduces to equation (3). Numerically let us take a typical value of $\sin\theta_o$ as 0.5, assume B_m 10 dB and α 0.2 as above, when we can predict L as 25 dB. Goertner (Ref 4) implies that typical losses may be of order 20-25 dB, although there are many additional factors in her work.

9. The writer has already presented the second example, in Ref 2. The bottom is modelled as a perfect fluid with total internal reflection and negligible losses up to a critical angle ϕ_c, and with heavy losses for steeper angles. Note that the steepest ray angle occurs at the vertex of the hyperbola, where, eg from equation (6), $\phi = \theta_o$, although of course $\gamma = \pi/2$. Thus if θ_o is less than ϕ_c the turn-round loss L will be negligible, but if θ_o is greater than ϕ_c the loss L can be quite large. It may be argued that this example is less realistic than the first. But both examples combine to show that low values of L arise with low values of θ_o, because the ray manages its turn-around without ever becoming steep.

4. EFFECTS OF FINITE SLOPE

10. The above description omits many points of practical importance, and we concentrate here on various finite slope effects. There is also the possibility of layering and especially of ducting, although with α small this disturbs the above formulae by a surprisingly small amount. The sound coming back from the bottom may do so after penetrating quite deeply inside it, and some consequences for slope propagation are discussed in Ref 5. The slope may be variable and the bottom quite uneven. A computer treatment may then be appropriate. Attention is also drawn to an alternative approach in which the slope returns are modelled by a scattering rather than a specular reflection process, this may often be appropriate if source or receiver are at short range.

11. With finite slope let us note as a first point that care is needed with the geometry. For example an outgoing ray after its last bottom bounce may be either upgoing or downgoing, α is not small in comparison with the ray angles, and one must be wary in applying the concepts of ray invariance or characteristic time.

12. Second, with finite slope there will be a finite number of reflections, and an integral may not give a good approximation for the summed bottom losses. In the extreme case with $\alpha = \pi/2$ we have a smooth vertical precipice. We might expect the turn-round loss to be low, and in fact for $\phi = 0$, assuming the sine dependence of bottom loss we have

$$L = B(\theta_o) = B_m \sin \theta_o . \tag{9}$$

This compares with an equation (8) prediction of $(2B_m \sin \theta_o)/\pi$. For such an extreme case the error factor of $2/\pi$ may be considered reasonable. The agreement with equation (8) is improved if we allow incidence with finite values of ϕ and γ.

13. There is also rapid improvement as α is reduced. Thus for $\alpha = \pi/4$, $\phi = 0$ in deep water, sine dependence and propagation directly upslope the actual turn-round loss is $1.41\ B_m$. The equation (8) prediction is $1.27\ B_m$.

14. Third, after turn around there may be an error in the final or deep-water value of ϕ. Let us consider the different possibilities, some of which are shown in Figure 2. Note that it is often helpful to use an alternative presentation in which the various mirror images of the wedge join at the vertex, and the ray path is represented by a single straight line.

a. Condition for initial and final deep-water values of γ (and ϕ) to be zero. First and last bounces will be at bottom. Middle bounce will be orthogonal to one of the boundaries. $\pi/2\alpha$ must be integral and equal to number of bottom bounces n. Inward and outward paths will be coincident in the γ plane. Figure 2(a) is an example.

b. Condition for initial and final values of γ to be the same: assuming first and last bounces are at the same boundary. Middle bounce orthogonal to one of the boundaries so that initial γ and α are related, but $\pi/2\alpha$ not necessarily integral. Inward and outward paths coincident in the γ plane.

c. Condition for initial and final values of γ to be the same: assuming first and last bounces are at different boundaries. $\pi/2\alpha$ integral and equal to n. Figure 2(b) is an example, which happens to be symmetrical. Like figure 2(c) the paths can go with or against the arrows. The result

here shows that the "retrodirective" property as in a radar reflector is not restricted to the right angle case $\alpha = \pi/2$, note also that three-dimensional forms may be specified with four (or three) reflecting walls. The condition here is related to the necessary and sufficient condition for the exact or perfect closure of the wedge and its ring of images, ie that π/α be integral. The extra cases with π/α odd correspond generally to initial and final values of γ which are symmetrical with respect to the surface and bottom slopes. For perfectly rigid or perfectly compliant boundaries the π/α integral condition leads to a simplification in the wave description of the field since there is no extra term due to diffraction at the apex (Ref 6).

d. General case: initial and final values of different. The difference or error in γ can be up to α, though in general the error in ϕ will be less than in γ. Figure 2(c) is an example, chosen with γ initially zero.

15. To see the significance of these angle errors we must move a stage nearer reality and consider coupling with a duct. The steepest angles in the main sound channel are of order 0.25 radians, so that an error of this magnitude will be liable to reduce the energy coupling into the duct. (For a short range source the duct coupling might sometimes be increased.) Slopes of this value are certainly not uncommon. If there is a depressed sound channel present, as in much of the North-East Atlantic, the outgoing sound will normally couple into it rather than into the main channel. The steepest angles in a depressed channel are typically around 0.1 radians, corresponding to a very common value of slope. The resulting finite-slope effects will be smeared out by variations in the initial value of ϕ, in θ_o and in α; but it seems there should often be an overall loss.

16. Fourth, the above errors in the final value of ϕ will be accompanied by errors in the final value of θ. But these will be of second order and of dubious import.

CONCLUSIONS

17. The simple equation (8) is commended as giving the flavour of the turn-round loss, its magnitude and dependences. With finite slopes there may be extra effects, especially when the coupling to a duct is spoilt.

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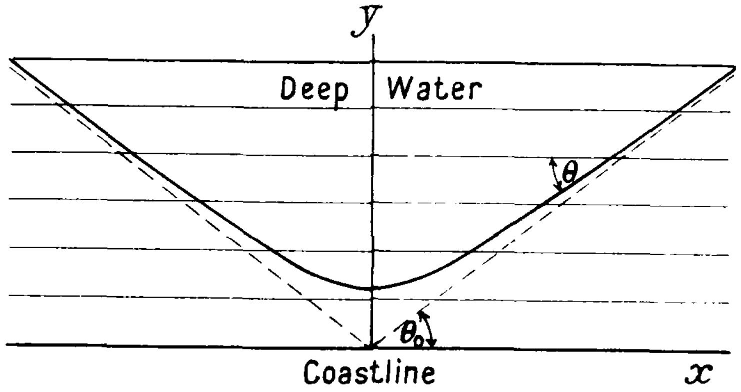

FIG 1 HORIZONTAL PROJECTION OF RAY PATH OVER A GENTLY SLOPING BOTTOM, FROM REF 2

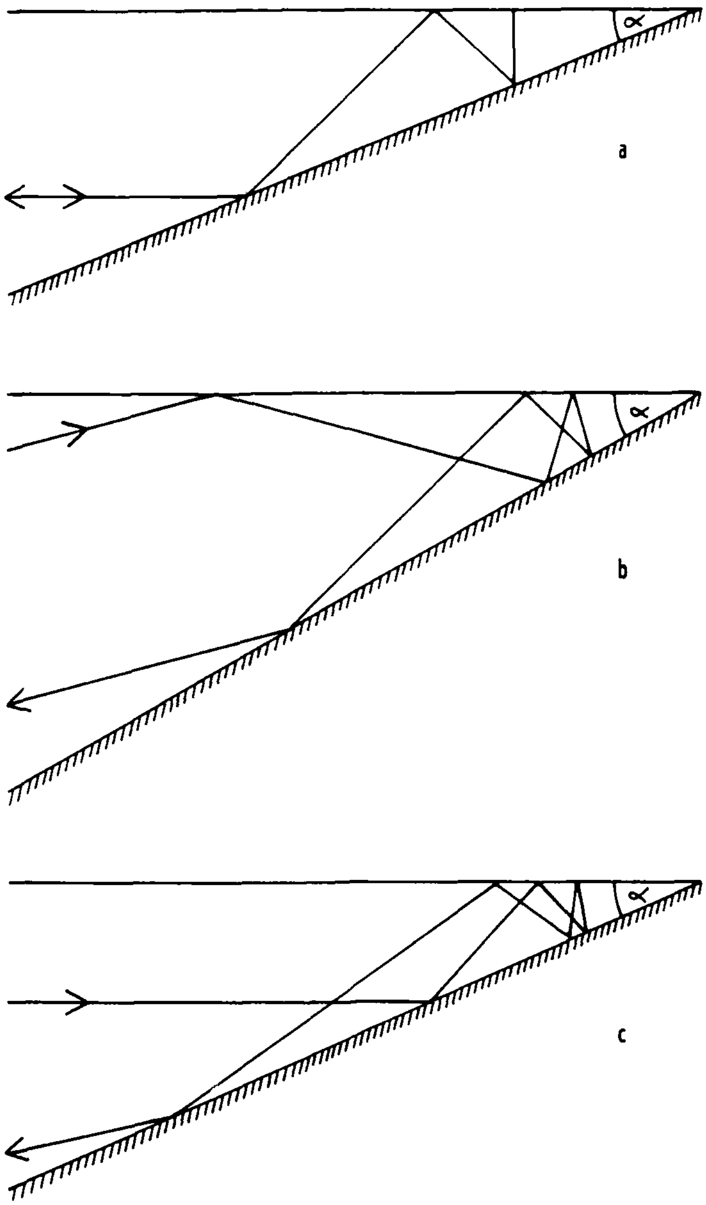

FIG 2 EXAMPLES OF RAY PATHS IN THE γ PLANE, PATHS RESOLVED ORTHOGONAL TO THE CONTOURS

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For oceanic sound reflected from a region of bottom slope the turn-round loss equals the sum of the bottom losses, and can be quite low if the total deflection in horizontal angle is low. Simple formulae are derived, and the effects of the slope being finite are discussed.

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